Section 22 Connecticut

The Physical Environmental Effects of Sand and Gravel Extraction in the Naugatuck River and Adjacent Floodplain

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New England Division

PREFACE

This research was conducted for the State of Connecticut, Department of Environmental Protection (DEP) under the authority of Section 22 of Public Law 93-251, Planning Assistance to States. The study was performed by the Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), in fulfillment of reimbursable order number 86-C-0043. Overall project management and funding was provided by the Army Corps of Engineers, New England Division (NED).

The report was written by Ms. Anne MacDonald of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL, at WES. Mr. Lawrence R. Oliver of NED's Planning Division was the environmental project manager. Mr. Thomas Morrissey and Mr. Art Mauger of DEP's Water Quality Compliance Unit provided valuable help during the study. Dr. Nelson Nunnally, of the University of North Carolina, Charlotte, and Mr. Robert Larson, of the Engineering Geology and Rock Mechanics Division, Geotechnical Laboratory, WES, acted as technical reviewers.

The work was accomplished under the direct supervision of Drs. F. Douglas Shields, Jr. and Paul R. Schroeder who served as Acting Chiefs, WREG, and Dr. R. L. Montgomery, Chief, EED, and under the general supervision of Dr. John Harrison, Chief, EL and Dr. John Keeley, Acting Chief, EL. COL Dwayne G. Lee, CE, was the Commander and Director of WES, and Dr. Robert W. Whalin was the Technical Director.

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THE PHYSICAL ENVIRONMENTAL EFFECTS OF SAND AND GRAVEL EXTRACTION IN THE NAUGATUCK RIVER AND ADJACENT FLOODPLAIN

by

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p 12, line 22: change "102,000" to "46,300"

p 12, line 23: change "85" to "95"; change "26,600" to "13,500"

p 16, line 21: change "770,000" to "1.2 million"

p 18, line 9: change "12" to "89"

p 18, line 11: change "25" to "188"

p 18, line 12: change "232" to "1770"

p 18, line 21: change "60 tons/mi^2/yr" to "60 tons/mi^2/yr; a specific gravity of 1.2"

p 18, line 29: change "4030" to "2020"

p 18, line 32: change "4260" to "3788"

p 18, line 33: change "280" to "320"

p 21, line 23: change "69" to "528", "12" to "89", and "73" to "561"

p 24, line 13: change "47" to "360"

THE PHYSICAL ENVIRONMENTAL EFFECTS OF SAND AND GRAVE EXTRACTION IN THE NAUGATUCK RIVER AND ADJACENT FLOODPLAIN

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ABSTRACT

Gravel extraction at five sites along the Naugatuck River in western Connecticut is of sufficient magnitude that recovery of the channel to pre-mining morphology is expected to require up to several hundred years for instream sites and longer for riparian pits. Peak flows are controlled by a number of reservoirs in the watershed, and sediment supply to the channel from hillslopes and streambanks is severely limited. The permanence of gravel pits in or near the channel has serious implications for improving water quality sufficiently to justify the reintroduction of an anadromous fishery.

Air photo analysis indicates that the Naugatuck River is an historically stable channel, even following the flood of record in August 1955, which had a discharge nearly 12 times greater than the mean annual flood, and a flood of similar magnitude two months later. Gravel bars observed at low water in the channel both pre- and post-flood are generally lateral or point bars rather than medial bars, suggesting low to moderate rates of sediment transport. Lateral erosion was detailed adjacent to the two instream pits and three riparian pits of interest to this study. Where the channel is confined by bedrock valley walls, natural lateral erosion associated with, and subsequent to, the 1955 floods is negligible. Instead, bars which formed between 1951 and 1963 (dates of aerial photography which bracket 1955 floods) have since degraded and been stabilized by vegetation, as would be expected under the current flood control regime. Only in unconstricted reaches are unpaired terraces found; these are formed from lateral erosion by the stream channel. Two of the riparian pits are in such a reach, and are likely to be incorporated into the main channel at some time in the future if remedial action is not taken. Lateral erosion in this reach is not systematic, however, so it is not possible to predict exactly when this will occur.

A review of the instream gravel mining literature is included in this report. Most of the published material relates to ephemeral and/or sand-bedded rivers, so is of limited applicability to this case. An annotated bibliography of this literature and material related to the geomorphology and hydrology of the Naugatuck River is included.

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PART I: INTRODUCTION

The Naugatuck River is a major tributary to the Housatonic River and drains 308 sq mi in western Connecticut (Figure 1). Due to its origin as a glacial outwash channel, substantial deposits of sands and gravels are found in terraces, the active floodplain and valley fill below the riverbed. The remainder of the watershed is covered by shallow soils and local veneers of till overlying crystalline gneissic bedrock. Therefore, fluvial and glacio-fluvial deposits in the narrow river valley represent the only local source of sand and gravel for the urban areas from Torrington south to Seymour (Valleta 1976). Past sand and gravel mining within the channel has resulted in long reaches of significantly enlarged active channel cross section; water in these reaches is virtually stagnant at low flows, with reportedly significantly depleted dissolved oxygen (DO) concentrations. Present mining in the flood-plain adjacent to the channel poses a potentially similar problem should the river thalweg be diverted through the gravel pits at any time.

The purpose of this study is to provide a base of information for more detailed study and preliminary decision-making regarding the impacts of streamside and instream gravel mining on the environmental resources of the Naugatuck River. This study was prepared to support the U.S. Army Corps of Engineers New England Division, (NED) in providing Section 22 assistance in response to a request by the Connecticut Department of Environmental Protection Water Compliance Branch. The State of Connecticut has a long term goal of reintroducing an Atlantic salmon fishery to the Naugatuck River, and current water quality reforms are geared to this goal. Suitable physical habitat, as well as good water quality, are necessary prerequisites to a viable fishery. It is therefore important to understand how gravel mining, which constitutes a major alteration to this river, is likely to influence both the long term quality of the physical aquatic habitat and physical variables which influence instream water quality.

The following sections of this report address these issues: the effects of instream sand and gravel mining on river channel morphology; regional and basin geomorphology; and mining history and characteristic processes of

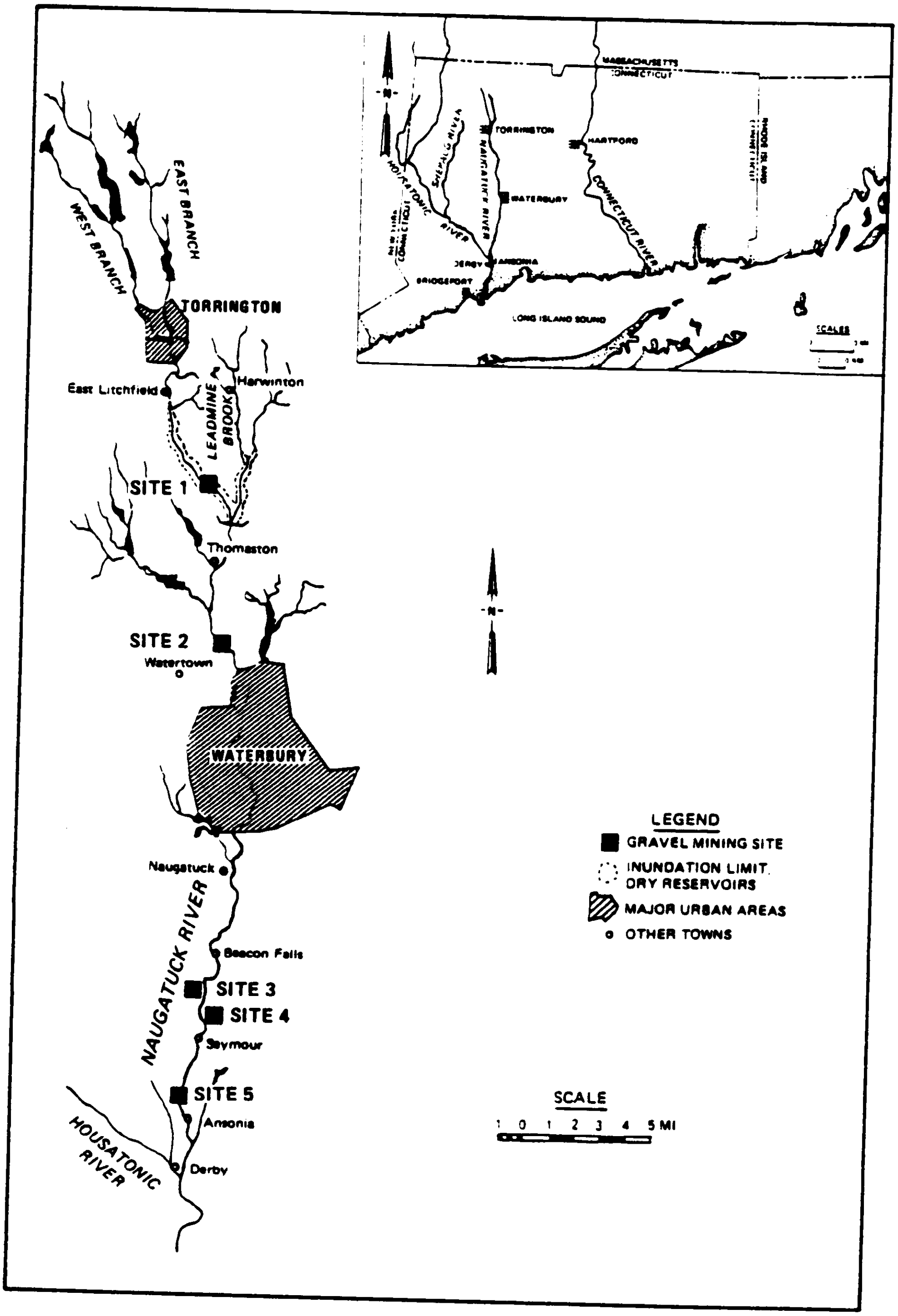

Figure 1. Location of the Naugatuck River study sites, western Connecticut

channel behavior at each site. The analyses reported herein are based solely upon existing data and unrectified sequential aerial photography, supplemented with field inspections. A more thorough study of the channel (and specifically, the gravel mining sites) may be required prior to any action to further the goals of the State of Connecticut.

PART II: EFFECTS OF SAND AND GRAVEL EXTRACTION IN RIVERS AND FLOODPLAINS

Most of the sand and gravel mined in the United States comes from off-channel locations. The most widespread and severe man-made alterations to stream channels are related to channelization, impoundment, and watershed-wide land use changes. In addition, modeling of alluvial channel response to any alteration is still an inexact science, and detailed analysis of local channel changes requires a great deal of site specific knowledge. As a result, little specific information on possible physical effects of sand and gravel mining in rivers and adjacent floodplains is available. An annotated bibliography of relevant literature is included as Appendix A.

Probable short term effects of mining on water quality are summarized by Bowen and Harp (1986), and are broadly related to downstream effects of sediment and sorbed chemicals (nutrients, heavy metals and organics) put into suspension by the extraction of the sand and gravel. They note longer term water quality effects due to stagnation of water in pits prior to natural refilling (including depressed DO and elevated CO_2 levels). No data from case studies are presented, however. The magnitude of these effects is likely to be site specific, and related to bed material sediment size and mineralogy, pollutant levels in the channel, and the magnitude of the extraction relative to sediment transport rates in the channel.

The most detailed discussion in the literature of the effects of sand and gravel extraction on channel morphology is that of Simons, Li and Associates (1982) and Li and Simons (1979) based on their consulting experience. The magnitude of any channel change, they reason, should be a function of the magnitude of instream sediment extraction relative to the supply of sediment delivered downstream to the site. Effects to be expected are those associated with a re-establishment of channel grade at the site: headcutting associated with the upstream face of the pit and local erosion of the downstream lip, possible bank erosion if the banks were oversteepened during mining, and filling of the pit with coarse bedload, thus temporarily severely restricting the downstream supply of such sediment. The work of Moore (1970, 1972) suggests that eddies formed due to vertical pit faces and sharp channel asymmetry may effectively prevent fine material (silt, clay and fine sand) from permanently depositing in pits. Limiting conditions for such eddy formation are not adequately known, however.

Floodplain sand and gravel pits immediately adjacent to river channels eliminate the water quality problems associated with instream pits so long as they remain not directly connected to the channel. However, they generally cannot be expected to fill by natural delivery of fluvial sediment. Furthermore, as both overbank flows and lateral migration of rivers must be expected, determining the minimum buffer configuration between a floodplain pit and the channel requires detailed site specific flow routing and sediment modeling. Simons, Li and Associates (1982) suggest that headcutting in a floodplain pit can be controlled with engineered structures or terracing of the pit walls. Breaching of the berm on the riverward side can be controlled with bank protection measures. The last alternative is to construct a sufficient buffer to accommodate any headcut of the pit.

Pit reclamation literature does not consider instream pits. Several alternatives for the reclamation of floodplain pits have been considered depending upon site characteristics, ranging from wetlands for wildlife (Potter 1983) to municipal waste disposal (Roxburgh 1983). All reclamation should minimize offsite effects (particularly relating to water quality) and quickly establish appropriate vegetation on the site (Geizer and Feldman 1979). Re-establishment of vegetation requires either prior stockpiling of topsoil or the planting of pioneer species (Newey and Lewis 1976; Oneth 1977).

PART III: GEOLOGY, GEOMORPHOLOGY AND HYDROLOGY OF THE NAUGATUCK RIVER WATERSHED

Proterozoic to Mid-Holocene Geology and Geomorphology

The Naugatuck River watershed is developed on crystalline gneisses and granites; these are of Proterozoic age (2.5 Ga to 570 Ma) in the Berkshire Highlands of the northern basin to Cambro-Ordovician (570-440 Ma) in the south. Schistose rocks, which are more foliated and therefore slightly less resistant to erosion, are present locally near East Litchfield and between Naugatuck and the mouth of the river at Derby, where lenses of the Devonian Straits Schist crop out (Rodgers 1982) interfingered with the main gneissic bodies. Many of the gneissic and granitic bodies are domal, forming major topographic highs; the general structural grain of the watershed is north-northeast to south-southwest. These structural tendencies have controlled erosion of the watershed during Pleistocene (2 Ma to 10,000 years B.P.) glacial advances, which left thin veneers of till overlying bedrock and 400 ft and deeper valleys with glaciofluvial material in them. These valleys, originally glacial meltwater channels, are now the dominant river drainages in the Naugatuck watershed; many are aligned parallel to structure, forming a modified dendritic/rectangular drainage pattern.

No detailed geomorphic studies have been done in the Naugatuck River watershed. However, Burnett (1980) evaluated the Holocene fluvial history of the nearby Housatonic River. The results of his study are generally applicable to the Naugatuck River. Glaciofluvial materials recognized in the Housatonic River valley are of two types: kame terraces or outwash valley fill. Kame terraces are discontinuous stratified sands, silts and clays with a gravel cap, which were deposited between a valley-filling glacier and bedrock high on the valley sides. Although these have not been differentiated from other glacial deposits on geologic maps of the Naugatuck valley, deposits with characteristic kame terrace morphology are or have been locally exploited there for sand and gravel.

Of more commercial and volumetric importance are outwash deposits, which filled the river valleys of New England as glaciers retreated at the end of the Pleistocene, and have been incised and reworked since deposition in response to local and base level (sea level) changes. Burnett (1980) found that these deposits had been cut downward into by the river in the Housatonic valley until ~ 2500 years ago, forming either paired or unpaired terraces. Where paired terraces were found, the valley was over-widened as a result of gouging of soft marble bedrock in the valley sides by glacial action. This was particularly common upstream of New Milford township (Rodgers 1982). Paired terraces resulted from the dominance of simple incision over incision accompanied by lateral erosion of the river banks. The cessation of incision has resulted in a very stable channel in these locations. Unpaired terraces were found to coincide with narrower bedrock valley sections, where the river laterally reworked as well as incised the outwash deposits in the early to mid-Holocene; since then, only lateral movement of the channel has occurred.

In the Naugatuck River valley, the areally extensive outwash deposits are limited to tributary mouths and, to a lesser extent, areas of schist bodies; there is no marble or similarly soft bedrock. Not surprisingly, major urban centers of Ansonia/Derby, Waterbury and Torrington have developed on the most extensive of these outwash deposits. Otherwise, unpaired terraces are the norm throughout the valley, demonstrating that lateral erosion has been geologically dominant. Where the valley is particularly constricted, such as downstream of East Litchfield or between Naugatuck and Beacon Falls, there are no terraces or floodplain deposits.

The Effect of Historic and Current Hydrologic Regime on River Morphology

The Naugatuck River has experienced 21 recorded floods from 1691 through the two floods of August and October, 1955 (Thomson et al. 1964). Although flood peaks generally result from high rainfall on a melting snowpack in the late winter and spring, a third of these floods were due to fall coastal storms or hurricanes; the 1955 floods both accompanied hurricanes. The peak discharge from the August flood at the Naugatuck gage was estimated at 106,000 cfs, or 11.8 times greater than the mean annual flood (Wilson et al. 1974), and is the flood of record. Despite the magnitude of the August 1955 event, hillslopes and river channels remained remarkably stable (Wolman and Eiler 1958). Exceptions to this pattern were: headwater streams, which were flushed of stored sediment; reaches of larger rivers where they flowed in narrow valleys, which eroded laterally; and areas where alteration by man resulted in disrupted runoff (such as along abandoned road courses) or constricted stream channels. Sediment transported by small channels was commonly deposited as debris fans, while that carried by larger channels was deposited on floodplains as thin, discontinous veneers of silt and fine sand. Wolman and Eiler (1958) estimated that these overbank deposits covered only 15% of the inundated area of the Farmington River valley east of Torrington, and that such deposits exceeded 0.1 ft in thickness on less than 3% of the flooded valley. Following those floods, the Army Corps of Engineers constructed Thomaston Dam, a dry reservoir which impounds water at discharges in excess of ~1000 cfs, a series of smaller flood control dams, and a local protection project in Ansonia/Derby. This has reduced the magnitude of peak flows considerably: Q_{25} from 45,000 cfs to ~19,000 cfs; Q_{10} from 20,000 cfs to 13,000 cfs; and $Q_{2.33}$ (mean annual flood) from 9000 to 6800 cfs.

In an attempt to put the 1955 floods in geo-historic context, Patton (1981) evaluated debris fans from tributary mouths, Holocene terrace deposits, and active floodplains in the Shepaug and Housatonic Rivers regarding their usefulness as indicators of paleohydrologic events. Debris fans were found to be formed during relatively high frequency/moderate discharge events (ex., ~ Q_{20}) relating to flushing of discrete reaches in the tributaries; these fans represent current watershed conditions and were not good indicators of discrete, very large floods. Slackwater deposits, a commonly useful indicator of high magnitude floods of regional extent, were found at tributary mouths and above bedrock constrictions along the Housatonic River valley. No floods of a specific, consistent regional magnitude could be matched with these deposits, however, leading Patton (1981) to conclude that the overall valley morphology developed throughout the late Holocene due to localized, rather than regional, conditions.

This pattern appears to hold true with the Naugatuck as well. Aerial photography was examined for evidence of channel aggradation, degradation and lateral instability from Torrington to the confluence with the Housatonic. Particular attention was paid to the channel 1 to 2 miles above and below all sites. Photography from 1951, 1963 (B&W, nominal scale 1:15,840), 1970, 1980 (B&W, nominal scale 1:31,680) and 1985 (Color IR, nominal scale 1:24,000) was evaluated using unrectified stereo pairs, except for the 1985 series, which was enlarged beyond the size suitable for viewing in stereo. Without rectification or nearby ground control, only a qualitative analysis of stability is possible (Miller 1986). Gravel bars within the channel are generally found only at bends or expansions in the valley, and are extremely stable for the period covered by aerial photography, 1951 to the present. The bars are almost always point or lateral bars and attached to the stream banks, supporting the notion of long term stability (Church and Jones 1982). Exceptions occur downstream from human activities (ex., urbanization in Waterbury ~1951, construction of the Route 8 freeway from 1960 through the late 1970's, and channelization at Torrington, Thomaston and Ansonia/Derby between 1963 and 1970).

Currently, sediment delivered to the channel comes from upland erosion of till and small outwash deposits, or from the bed and banks of the Naugatuck River itself. Disturbance of the land surface by urbanization, road building, mining and cultivation also increases the sediment available to the fluvial system. A report of the Connecticut Council on Soil and Water Conservation (1979) summarizes results of an inventory of measured soil loss at disturbed sites throughout Connecticut. The study focussed on soil loss from cropland, construction sites, streambanks, road embankments and surface mines, and excluded urban areas from the sample. The Universal Soil Loss Equation was used to estimate the amount of erosion at each site in excess of geologic rates; no attempt was made to determine how much of the eroded soil was delivered to any watercourse (the sediment delivery ratio). Based on this study, the minimum annual approximate soil loss in the basin above Watertown (Litchfield County) is 280 tons/sq mi/year or 102,000 yds^3/year; for the lower basin, that figure is 85 tons/sq mi/year or 26,600 yds^3/year. By analogy with Yantic River basin data storage in impoundments and tributary basins restricts the amount of sediment expected to enter the Naugatuck to about 1/4 of the total yield from hillslopes (Kulp 1983).

No channel surveys were available to determine long term channel changes, although a comparison between the Flood Insurance Report for Harwinton Township (Federal Emergency Management Agency (FEMA) 1981) and the 1969 revision of the Thomaston 15' topographic quadrangle showed local aggradation in the range of 5-10 ft. Hydrographers' notes from the USGS gaging station at Beacon Falls were examined for signs of aggradation or degradation from 1956 (when the station was established to replace the one at Naugatuck lost during the 1955 floods) through 1986. The maximum aggradation was an average of 1.3 ft across the channel bed between March and April, 1958; most of this sediment was removed by May, 1959. However, the channel has continued to aggrade very slowly at this location and is now approximately 0.7 ft above its original 1955 elevation.

PART IV: GEOMORPHIC PROCESSES AFFECTING INDIVIDUAL GRAVEL EXTRACTION SITES

Erosion and deposition along the bed and banks of the Naugatuck River will, over time, modify all of the gravel mining sites included in this study. The extent of these modifications over the past 35 years has been preliminarily evaluated using available aerial photography and archival data on the hydrologic regime of the river. This synthesis, along with observations obtained on site, is used as a basis for examining the probable future modifications to the site in the absence of active site management. In particular, such questions as the "life" of excavations (for instream pits) and the rate of lateral migration of the channel (toward floodplain pits) are of interest. A more involved analysis of the aerial photography and collection of detailed site geometry and materials data will be necessary to answer these questions with precision.

The results of this reconnaissance study indicate that instream pits are likely to be long lived, and that lateral migration of the channel across the floodplain is generally minimal even in the presence of the flood of record. Local exceptions to this can be found, however, and may be significant in the context of gravel mining. The pattern of slight bar growth between 1951 and 1963 and subsequent degradation, stabilization and/or invasion of vegetation, occurs throughout the basin and does not appear to be directly related to instream mining. Rather, this pattern is an expected consequence of large floods (two in 1955) followed by active flood control (from Thomaston and other dams), channel bank stabilization (along the reconstructed Route 8 and downstream at Ansonia and Derby), and sufficient sediment delivered from tributary channels due to urbanization to compensate for any decreased bed erosion.

Instream Pits: Sites 2 and 5

The life of an instream pit is determined by the rate of filling by geologic materials; this is in turn a function of the delivery of sediment to the pit from upstream or from the adjacent floodplain and hillslopes and the degree to which this sediment is retained within the pit. If all entering sediment is retained within an instream excavation for a sufficiently long period of time, channel degradation downstream of the pit is an issue. Finally, depending upon pit geometry and the material in the channel bed upstream, the development of an upstream migrating headcut is also possible.

Along the Naugatuck River, degradation related to mining should manifest itself as either a) a greater reduction in the total area of gravel bars than that observed along the rest of the channel (or in the reach of interest prior to gravel mining) or b) a narrowing of the channel, as the cross sectional area adjusts to a lowering of the bed. Bank failure due to oversteepening (by lowering the bank toe elevation) is likely only in areas of non-cohesive banks and/or rapid degradation; bank vegetation and coarse, infrequently mobilized streambed material preclude this mechanism of channel adjustment from being significant here.

Site 2

At Site 2, between the Penn Central Railroad bridge south of Thomaston and the bend upstream of the Frost Bridge near Watertown, two large instream pits were excavated between 1963 and 1970 (Figure 2). Further, less extensive

Figure 2. Looking downstream at Site 2, an abandoned, in-channel pit

excavation occurred in the channel between these original pits after 1970 and prior to 1980, by which time activity within the channel ceased. Approximately 5100 ft of river channel have been disturbed by gravel mining at this site. Average width in the reach, measured from aerial photography, has increased from 175 to 225 feet and average depth has increased by over 6 feet. The maximum pit depth shown on a 1980 hydrographic survey of this site was ~ 25 feet. Between 1951 and 1963, gravel bars between Thomaston and the site grew slightly and were destabilized (i.e., detached from the banks or stripped of a significant amount of vegetation), probably as a result of floods in 1955. Bars within the site limits and for several thousand feet downstream were degraded or more vegetated in 1963 than in 1951. During the first mining phase, upstream bars stabilized, bars at the site were extensively mined, and bars below the site were degraded or removed entirely. Upstream headcutting at the site has been prevented by a bedrock outcrop, which acts as a grade control (Figure 3). Except for small gravel deposits upstream of the site at the mouth of Branch Brook, there was little change in bar morphology, and a slight increase in bar vegetation, from 1970 to the present.

The volume of material removed from Site 2 was estimated based on a hydrographic survey of the site from 1980, assumptions of the pre-mining bed elevations based on 1963 aerial photography and a reasonable bankfull channel conveyance. At least 770,000 cubic yards of material would be required to return this site to a channel geometry equivalent to that observed in 1963. It is excavations of this magnitude which pose the most serious threat to water quality and hence to migration of anadromous salmonids. Time of travel studies during summer low flows of 20-40 cfs reportedly give a mean water velocity through the site of ~0.03 fps; average velocities at the most heavily excavated cross sections would be an order of magnitude lower.

Estimated bedload transport rates were based on the entrainment function proposed by Milhous (1987) and the empirical stream power-instantaneous bedload transport rate relationship determined from the Snake and Clearwater Rivers (Klingeman and Emmett 1982). These rivers are gravel-bed channels similar to the Naugatuck. It is likely that the sediment supply in the Snake and Clearwater watersheds is greater than in the Naugatuck catchment, and that bedload transport rates are larger in these western rivers than in the Naugatuck at comparable stream power values. A lack of detailed site information made such calculations employing more exacting methods of bedload

Figure 3. Downstream view from head of Site 2. The diagonal riffle seen in the middle of the photo is supported by a bedrock outcrop which functions as a grade control.

transport capacity unwarranted; however, all assumptions concerning site characteristics were conservative, designed to over-estimate actual bedload transport.

Channel geometry was estimated from 1985 aerial photography and the Flood Insurance Report for Thomaston (FEMA 1982). Size of the surficial bed material was based on pebble counts immediately above the site, and was used to determine the threshold of bedload transport; size of the subsurface material was assumed to be equal to the material in adjacent outwash/fluvial terraces, and was used for the gross sediment transport in excess of the threshold. Median sediment size was 100mm for the pavement (surface) and 30mm for the subsurface material immediately upstream of the site; these dimensions were assumed to hold for reaches upstream as well. Discharge estimates were based on those given in the Thomaston Flood Insurance Study (FEMA 1982), with some modifications resulting from relatively high flood peaks in the 1980's. Specifically, a re-analysis of the record of the USGS Gaging Station at Beacon Falls required upward revision of the magnitude of flood discharges, such that the magnitude of the 10 year flood reported in the 1978 Flood Insurance Report for Beacon Falls is actually equivalent to Q_5. The new estimate of Q_{10} is 135% of Q_5, and Q_{bf} is 46% of Q_5. These proportions were used to adjust estimated peak discharges listed in flood insurance reports throughout the basin.

Total bedload transport estimates for this site are as follows: for the reach 10-11,000 ft above Site 2, average transport capacity is 12 yds^3/yr (~0.5 tonnes/km^2/yr); for the reach 5000-6000 ft above Site 2, average transport capacity is 25 yds^3/yr (~0.9 tonnes/km^2/yr); and for the reach 0-1000 ft above Site 2, average transport capacity is 232 yds^3/yr (~7 tonnes/km^2/yr). These estimates further assume no limit on sediment supply, although construction of Thomaston Dam, low rates of urbanization upstream, and boulders exposed in the channel in the 1000 ft above the site all suggest that there is a restricted supply of mobile sediment; these estimates of bedload transport represent an upper limit on actual movement of bed material.

The size of the excavations at Site 2 are sufficient to trap suspended sediment as well. The amount of suspended sediment deposited in the pits annually was calculated using an estimated suspended sediment yield of 60 tons/mi^2/yr and weighting trap efficiency according to the method of Churchill (1948, in Vanoni 1977). This estimate of annual yield of suspended sediment in the Naugatuck River is based upon extrapolation of measured suspended sediment yield in the Yantic River (Kulp 1983), as corroborated by soil loss estimates for the Naugatuck River watershed (Conn. Council of Soil and Water Conservation 1979). Although hillslopes are slightly steeper, the upper basin of the Naugatuck River (above Waterbury) is relatively similar in land use and geology to the Yantic River watershed. The total maximum suspendable sediment trapped at Site 2 is estimated at 4030 yds^3 per year.

The estimated pit volume at the site was compared with calculated bedload and suspended load upstream of the site to determine approximate longevity of the excavations. The total fill is estimated to be 4260 yds^3 annually. Based upon this figure, Site 2 will fill in ~280 years.

Site 5

Less information is available for Site 5, located on the outside bank of the bend immediately below Kinneytown Dam (Figure 4). The area below the dam

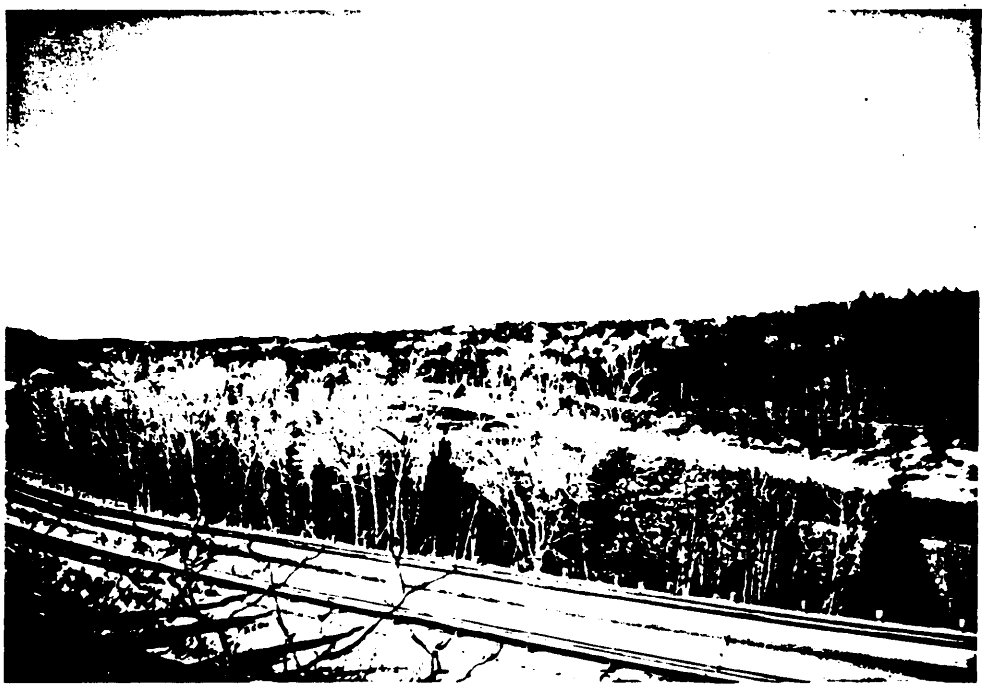

Figure 4. Site 5, flow is from left to right. Note mid-channel bars. Route 8 is in the foreground

apparently received a great deal of sediment following the 1955 floods; the gravel bars at this location have been steadily degrading since that time, although interpretation of these features from photography is confounded by substantial water diversion at low flow at the dam site. Mining began between 1951 and 1963; a rectangular pit 800 ft long and 180 ft wide is plainly visible on the 1970 photos. The pit borders were slightly modified prior to 1980 (by fluvial action?) and were unchanged from 1980 to 1985. The current pit depth is not known. Channel bars between the dam and the site have successively degraded and become more vegetated since 1963. Channel changes upstream of the dam and downstream of the site are minimal and are primarily related to: redistribution of sediment during the 1955 flood; the low head dam (which was probably breached during the flood); construction of Route 8 (immediately uphill, west of the site); and construction of a channelized reach downstream as part of the Ansonia/Derby local flood protection project. Channel geometry and flood profiles calculated for the Seymour Flood Insurance Study (U.S. Department of Housing and Urban Development (HUD) 1978) show a relatively flat water surface above the pool during flood events; the dam should be an effective barrier to bedload movement as a result.

Floodplain Pits: Sites 1, 3 and 4

The direct environmental problems associated with floodplain pits are less severe than those associated with instream pits, providing that these excavations remain separated from the main river channel. However, incorporation of any of the pits at these sites into the channel could happen by several mechanisms including lateral channel movement or downcutting of a berm separating the pit from the channel. Therefore, the local rates of lateral migration of the river are of importance in these cases, as are the mining practices and actual channel and floodplain geometries at each site.

Site 1

Site 1 is located on the left bank of the river at the end of Wildcat Hill Road, between Torrington and the Thomaston Dam (Figure 5). Mining of outwash terraces above the floodplain is in evidence on the earliest aerial photographs and expanded continuously throughout the study period. The entire floodplain was disturbed by the time of the 1980 photography, which also showed the first evidence of mining in the wet. In addition, the width

Figure 5. Aggregate extraction from riparian pit at Site 1.

of the channel had doubled (from ~130 ft to ~260 ft) between 1970 and 1980, apparently as a result of mining. The 1985 photography shows three large and two small water-filled pits on the floodplain and additional bank retreat of ~40 ft. These observations from aerial photography and site visits show that there has been instream mining at this site with concomitant channel widening; the channel also appears to have deepened by an unknown amount.

As was the case at Site 2, the channel here does not show clear evidence of upstream or downstream degradation due to mining. Gravel bars upstream of the site began degrading after 1951 and were in the process of becoming stabilized by vegetation prior to any in-channel mining. Some bedload transported past the site in the 1955 floods was deposited in gravel bars downstream, which have also degraded slightly and become well vegetated since 1963.

At this site, the channel banks were stable throughout the period 1951-1970. This is not a site of extensive natural deposition or lateral migration, and the existing pits are not likely to become part of the channel without the aid of the mine operator. It is possible, however, that the channel as now formed could exhibit poor water quality at low flow. Without more details concerning the channel geometry, the life of the in-channel excavation cannot be determined. Bedload transport rates for upstream reaches were calculated, however, similarly to those calculated for Site 2. For successive reaches 10,000-11,000 ft, 5000-6000 ft and 0-1000 ft above the sites, average bedload transport rates were estimated at 69, 12, and 73 yds^3/yr. These calculations assumed that the median size of the surficial material was 115 mm and the median size of the subsurface material was ~45 mm in each reach, based on pebble counts of pool and riffle material at the site.

Sites 3 and 4

Sites 3 and 4 were evaluated together, as they are on alternate bars/ floodplain in a contiguous channel reach. Site 3 is on the right bank 800 ft below Pine Bridge, between Beacon Falls and Seymour (Figure 6). It has two wet rectangular pits totaling ~3200 ft in length and 300-400 ft in width; pit depth was estimated at 20-30 ft (F. D. Shields personal communication). Mining in the dry began at this location sometime between 1970 and 1980, with the pits excavated shortly thereafter. Apparently, the 50 ft wide berm separating the pits from the channel was overtopped near the upstream end during high water in 1982 (Q_{pk} = 15,600 cfs at the USGS gage 1.4 mi. upstream at

Figure 6. Looking downstream, Site 3 is on the right and the Naugatuck River is on the left. Note island at upper end of pit

Beacon Falls), creating a small island 500 ft south of the upper pit margin. In addition, the pits drain through a breach in the berm 2600 ft downstream of the upper margin; this outlet controls the water elevation in both pits, as the pond elevation was approximately 8 ft below river elevation at the upstream end during a site visit in April, 1986. [This cross-valley hydraulic gradient should be considered if and when measures are undertaken to permanently stabilize the berm.]

Site 4 is an oval pit, 920 ft on the north-south axis by 375 ft east-west, located on the left bank downstream of a trailer park complex, which itself is downstream of Site 3 (Figure 7). A small, dry pit is visible at the upstream end of the site in the 1970 photos, with the full pit excavated between 1970 and 1980. The 1980 photographs show the pit open at both upstream and downstream ends; any buffer was probably breached in the 1979 peak flows (Q_{pk} = 18,700 cfs at the Beacon Fall gage). This site, too, is now separated from the channel by a 50-60 ft wide, 20 ft high berm composed of unconsolidated sandy gravel (median grain size = 25mm).

Figure 7. Site 4, high banks of stockpiled material separate the channel and the pit

Given the history of these sites, breaching of the berms is a real concern. The upper half of Site 3, and all of Site 4, were sparsely vegetated or unvegetated gravel bars in the 1951 aerial photos; most of the vegetation at Site 3 was removed prior to the 1963 photos, and the area of gravel bar increased at the expense of downstream cultivated floodplain on the same bank due to bank erosion and overwash. A small mid-channel bar at Pine Bridge had extended in the downstream direction and attached to the left bank at its downstream edge. Streambanks on the convex bank of bends upstream to Beacon Falls experienced erosion locally in excess of 100 ft. This erosion, as severe as any along the entire channel during this time period, was probably in response to the flood of record in 1955 (Q_{pk} = 106,000 cfs at the Beacon Falls gage). Subsequently, the bars degraded slightly and revegetated from the streambank inward toward the channel centerline, except where disturbed by construction. Local revetment is visible on 1963-1985 photography. The channel banks above, adjacent to, and below the reach have been very stable since 1980.

A detailed evaluation of site geometry would be necessary to determine the likelihood of berms overtopping in the future. However, the upper two thirds of Site 3, and all of Site 4, were part of the active channel in 1951 photos, prior to significant flood control in the watershed. In addition, the berms are made of unconsolidated, poorly sorted (well graded), easily eroded material, which could fail by sapping during the waning stages of flood flows. Median grain sizes of the two berm samples from Site 4 were 0.25 mm and 50.7 mm. On the other hand, the recent pattern of the channel in this reach has been remarkably stable considering that it was a major depositional and erosional site during the 1955 flood(s). The channel crossing from left to right banks below Site 4 moved upstream ~350 ft between 1951 and 1963, and has been stable since. Estimated bedload transport in the reach, as calculated above, is moderate to low, about 47 yds^3/yr, or ~0.6 tonnes/km^2/yr. For comparison, calculated bedload transport rates in stable, gravel-bed channels of Colorado range from 0.05 to 1.0 tonnes/km^2/yr (Andrews, 1984).

PART V: CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations below are based on preliminary analysis, using existing data. Detailed channel geometry and sedimentologic characteristics needed for more precise predictions of channel behavior were not available.

a. Sand and gravel extraction has had a major effect on the morphology of the channel of the Naugatuck River over the last several decades. Long reaches of the channel have been widened and deepened. Effects of mining on overall channel stability have been minor. However, the influence of local channel changes due to mining on overall aquatic habitat are unknown.

b. Both instream and floodplain pits are expected to persist for many centuries under the current climatic regime. The probability of channel migration into floodplain pits is site specific, and difficult to assess precisely given the available data. This probability appears to be very low for the upstream most site, given local channel and valley characteristics. Channel banks at sites 3 and 4 have been stable for the last 30 years. However, two points should be noted: a) alternate terraces, such as those found at those two sites, are formed by the lateral migration of a channel within a confined valley; b) berms constructed between the pits and the channel were breached at Site 3 by a flood with 14 year recurrence interval and at Site 4 by a flood with a 27 year recurrence interval under the current flood protection scheme. Without reclamation, these pits will eventually become part of the channel, where they will then persist for several centuries.

c. Since the existing pits can be considered permanent features during engineering time (50-100 years), a moratorium on sand and gravel extraction from the Naugatuck River and its floodway should seriously be considered. The moratorium should last until information regarding the effects of existing pits on water quality and aquatic habitat are known.

d. A variety of measures are available to either restore or manage the existing pits. Although one approach would be to fill the pits with clean material, no obvious sources of such material were found during this study. Other measures could include: rebuilding of berms as necessary to maintain separation between river and floodplain pits; structural and/or vegetal stabilization of the berms; or bypassing pits with a constructed low-flow channel.

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APPENDIX A: ANNOTATED BIBLIOGRAPHY

APPENDIX A: ANNOTATED BIBLIOGRAPHY

PART I: PHYSICAL EFFECTS OF SAND AND GRAVEL EXTRACTION IN RIVERS AND FLOODPLAINS

Bowen P. T. and Harp, J. F. 1986. "Cumulative Effects of Sand Mining in Inland Rivers," Third International Symposium on River Sedimentation, University of Mississippi, pp. 1191-1199.

Ten percent of all sand and gravel extraction is instream, by one of 3 methods: dry pit (above water table); wet pit, using draglines; and other dredging, usually in public waterways in conjunction with navigation. This paper gives a general summary of impacts. The major physical impact is sedimentation from dredged material. No mention is made of impacts associated with instream mining (extraction in excess of safe yield) of sand and gravel, such as permanent changes in channel pattern, morphology, etc., except where extraction acts similarly to channelization in ephemeral and/or braided channels. Biological (water quality) impacts may include: reduced water velocity, leading to decreased DO and increased CO_2 and a resulting decrease in fish hatch and survival rates; decreased riffle habitat; increase in turbidity during mining, resulting in siltation of downstream riffles, direct harm to some aquatic organisms, decreased DO, and potential release of BOD/COD matter, nutrients and toxics in bottom sediment (although aquatic chemistry determines the amount of any compound released into the channel from sediments); and disturbance of benthic organisms, which are often eliminated entirely and must re-colonize a site following cessation of mining activities.

Bull, W. B., and Scott, K. M. 1974. "Impact of Mining Gravel From Urban Stream Beds in the Southwestern United States," Geology, Vol 2, No. 4, pp. 171-174.

The authors address probable and observed impacts of sand and gravel mining in the context of hydrologic changes associated with urban development (eg., increased flood peaks) and the southwestern United States, where inactive stream channels are commonly mined. They advocate use of repeat channel surveys (even of an informal nature) to monitor streambed changes due to gravel mining. They also present a case study of Tujunga Wash, an inactive channel on a large alluvial fan in the metropolitan Los Angeles area which was "sporadically" mined since 1925; during storm flows in 1969, flood waters were diverted into the wash, and much of the sediment in transport was trapped by gravel pits. More than 4 meters of scour, extending as far as 8-900 m. upstream of the pit in both the active and inactive channels, resulted in the loss of seven homes. The need for detailed, site-specific geomorphic analysis is emphasized; the authors feel that such an investigation would have shown how unstable the flow diversion out of the historically inactive channel actually was.

Li, R. M. and Simons, D. B. 1979. "Mathematical Modeling of Erosion and Sedimentation Associated With Instream Gravel Mining," Proceedings of the Specialty Conference on Conservation and Utilization of Water and Energy Resources, Hydraulics and Energy Division, American Society Of Civil Engineers, pp. 420-429.

This constitutes a more detailed discussion of the San Juan Creek, California case study noted below (Simons, Li and Associates 1982). The authors used a variation on the Meyer-Peter, Muller sediment transport equation to determine changes in geometry associated with degradation of the upstream pit face. Required data included storm hydrographs, some measured bedload transport rates to calibrate bedload formula for the site (and convert it to a total load formula), and detailed site and channel geometry. The amount of sediment trapped by pit during series of storms in 1969 gave a rough estimate of sediment transport rate for calibration purposes; morphologic changes to the pit during those flows were not noted. Sediment deposition in the pit was assumed to be transport limited, ie., with an ample supply of sediment from upstream and uplands. Pit depth was 48 feet, compared to upstream flood water depth estimated at 5-6 feet for a discharge of 13,500 cfs. San Juan Creek is ephemeral, in an arid environment, with the largest bed material in transport not exceeding 100 mm. Therefore, a headcut created in the 1978 storms is propagating upstream faster here than would be expected on the Naugatuck River.

Moore, B. R. 1970. "Scour and Fill Processes In A Deep River Hole, Ohio River, Louisville, Kentucky," Journal of Sedimentary Petrology, Vol 40, pp. 449-456.

This study examines a dredge hole in the Ohio River, which extends one third of way across the channel at its maximum width, 40 ft below normal channel bottom (which is 30 ft below normal pool elevation), and is located between two meanders near the same bank as an upstream point bar. Following dredging, the hole had near vertical walls of silt and sand, with coarse sand and gravel in the bottom from excavation of a coarse deposit at the base of the hole. Studies of the hole from dredging in 1966(?) through 1968 showed some headcutting at upstream end, tapering and scour in the cross section, and 3-5 ft of scour on downstream face. Lack of fill is attributed to the action of a vortex about a vertical axis, keeping bedload (silt and sand) suspended around hole. Fine to medium sand was deposited on closest shore (Ky.) from upstream moving currents, based on observed sedimentary structures. Observations with floats indicated that the vortex was developed at mean channel velocity of 2 fps, while the peak mean velocity for the highest discharge during the study was 3 fps. The vortex was initiated due to rotation induced by greatly reduced water velocity in vicinity of the hole with respect to the undisturbed channel.

Moore, B. R. 1972. "Hydraulic and Sediment Transport Studies In Relation To River Sediment Control and Solid Waste Pollution and Economic Use Of the By-products", Kentucky Water Resources Research Institute Report No. 59, University of Kentucky, Lexington, KY.

This report summarizes flume studies related to the dredge hole above and presents detailed bed material surveys of reaches of the Ohio, Kentucky and Big Sandy Rivers. A fill-scour-fill sequence was observed in the model dredge hole during passage of a simulated flood wave, with scour associated with the hydrograph crest. "Maximum trap efficiency occurs when the [normal] depth of the flume is twice that of the hole, and maximum scour conditions occur when hole and flume depths are approximately equal." It is not known whether configurations with the hole depth appreciably greater than the flume depth were used. Trapping of sediment was also lower for larger holes constructed immediately adjacent to the flume wall. [Note that later WRRI Report 81, dated 1974, reports no change in morphology of Ohio River dredge hole.]

Simons, Li and Associates. 1982. "Chapter XX, Case Study: Sand and Gravel Mining," Engineering Analysis of Fluvial Systems, Simons, Li and Associates, Ft. Collins, CO, pp. 10.1-10.63.

This is a discussion of three case studies outlining determinations of safe yield, channel morphologic changes, and sediment transport related to headcut migration, based on consulting analyses of instream and floodplain sand and gravel mining undertaken by this firm. Data required for detailed analysis of mining effects include: hydrologic regime, including current flood flow frequency; channel and pit morphology, such as that required for HEC-2 type flow routing; sediment transport and yield analysis; and local and general channel degradation and aggradation analysis. These data may then be used for site specific analysis, with channel morphologic changes due to a known discharge modeled. For two of the modeled/observed instream cases, where the upstream face of the pit was vertical, the first peak flows in a season removed most of the face and headcut migration began upstream. Additional peak flows further degraded the upstream face, with sediment deposited in the pit; in Rillito Creek, the "pivot point" of the headcut migrated 18 ft above a 2000 ft long pit.

It was also noted that the site geometry needs to evaluate the stability of floodplain pits are even more extensive than those for instream pits, because the problem must be dealt with three dimensionally, and most sediment transport models are one dimensional. Suggested alternatives for stabilizing floodplain pits included bank protection of main channel, the allowing of adequate buffer to incorporate headcuts, the construction of a drop structure at inflow locations and channels at outflow locations, and terracing the interior of the pit to prevent headcuts.

Site specific data presentation is spotty and no estimates of model error are given; furthermore, some important watershed-specific considerations are neglected. The overall approach is sound, however. For full details, reader will need to find all relevant consulting reports (including those produced prior to sponsors' consultation with Simons, Li and Associates) for the projects on: San Juan Creek (south coastal California), Rillito Creek (near Tuscon, Arizona) and Dry Creek and the Russian River (north coastal California). These streams are all located in areas of ample sediment supply and moderate to sparse riparian vegetation; furthermore, the first two streams are ephemeral. Therefore, the channel changes noted are extreme relative to those expected in the Naugatuck River.

PART II: SAND AND GRAVEL PIT RECLAMATION

Geizer, H. N. and Feldman, R. N. 1979. "A Model For Sand and Gravel Pit Reclamation," Geological Society of America Abstracts With Programs, Vol 11, No. 1, p. 14. [abs]

The authors incorporated the end use into the grading and mining plan. Detailed site analysis, including boreholes, resistivity logs, and detailed sedimentological description, allowed minimization of extracted volume. Such knowledge of site characteristics also allowed optimal development of site once reclaimed.

Oneth, H. W. 1977. "Reclamation of Sand and Gravel Mined Areas in New York," Journal of Soil and Water Conservation, Vol 32. pp. 151-153.

All mines with an annual production of > 1000 tons (600 cu. yds.) are regulated by the state of New York. The greatest concern of the state is off-site sedimentation (particularly that delivered to stream channels). Therefore, reclamation plans are required for permitting of extraction activities. Plans are favored which include reclamation during mining, which avoid pits of stagnant water, and which keep off-site sedimentation to a minimum. In return, Soil Conservation Service and state personnel are available for technical assistance, including analysis of: landforms, hydrology and cultural use adjacent to the site, haulage routes, and the reclamation plan itself, particularly grading plans, spoil disposal, drainage and revegetation. Stockpiling of topsoil for use in reclamation and the use of spoil to alleviate vertical and near vertical faces are noted. No particular attention was given to the needs of in- or near-stream pits.

Potter, J. L. 1983. "Reclaiming Sand and Gravel Pits For Wildlife," Proceedings of a Symposium on Surface Mining, Hydrology, Sedimentology and Reclamation, University of Kentucky, pp. 315-319.

The case is presented for the use of reclaimed sand and gravel pits, particularly shallow pits mined in the wet, as wildlife areas.

Sand and gravel is most commonly extracted in urban areas where wetland wildlife habitat is most endangered. In addition, sand and gravel deposits are usually clean, without toxic materials. For pits to be suitable habitat, they must be given physical diversity (islands, crenulated shorelines, etc.) and allowed to develop biological productivity, with appropriate nutrient cycling. Several design problems are best considered prior to mining.

a. Water regulation: the pit must hold water, which generally requires a silt or clay liner. However, pits hydrologically connected to lake or stream systems, even through rapid groundwater movement, will have fewer problems with eutrophication and stagnation.

b. Physical morphology should be designed to have suitable shoreline variation at all probable water levels. Banks should not be vertical; shoreline grades of 1:5 from low to high water marks and 1:25 from pit bottom to low water mark are recommended. These allow revegetation by both submergent and emergent plants, providing spawning habitat for fish, amphibians and macroinvertebrates.

c. Creation of islands should be accomplished where possible, perhaps from spoil material.

d. Rapid revegetation is necessary, although local natural rates may be sufficient in mild, humid climates depending upon the modes of propagation of local wetland species and distance to an undisturbed seed source. If planting is necessary, both pioneer and later successional species should be included.

Roxburgh, I. S. 1983. "The Reclamation of Worked-out Sand and Gravel Quarries Utilising Domestic Waste -- The Issue of Groundwater Pollution," Minerals and the Environment Vol 5, pp. 3-9.

Both sand and gravel and municipal wastes are high bulk materials sensitive to transportation costs, and either used or generated in urbanized areas. The filling of gravel pits with municipal waste has practical appeal. However, sand and gravel extraction from river terraces leaves a pit in a shallow aquifer, which is often directly connected to the river channel; fill of such pits by garbage could give rise to severe water quality problems. If local site conditions warrant, a disposal strategy designed to initially contain, then degrade, dilute and disperse any leachate may be devised which would protect (or not further degrade) water quality in the shallow aquifer and stream channel. A case study is presented utilizing this concept, where both the aquifer and stream were already polluted and therefore not potable. A leachate treatment area was constructed on the landward side of the pit/dump.

PART III: GEOLOGY, GEOMORPHOLOGY, AND PRESENT FLUVIAL ENVIRONMENT OF THE NAUGATUCK REGION

Burnett, A. W., 1980. "Fluvial Geology and Archaeology Of the Housatonic River Valley, Northwestern Connecticut," Unpublished B.A. thesis, Wesleyan University, Middletown, CT. (NTIS PB81-163602).

The channel of the Housatonic River has been at a stable elevation for the last 2500 years. However, the variation in the lateral stability of the channel during that period has been related to the prior modification of the valley by Pleistocene glaciers. Glacially derived kame terraces, and both paired and unpaired fluvial terraces are present though discontinuous in the Housatonic River valley. Kame terraces found along the entire river are characterized by coarse gravels overlying finer deltaic sands, silts and clays. They represent a major source of unconsolidated sediment to the fluvial system. Reaches with paired fluvial terraces are found where glaciers carved wide valleys in relatively soft marble bedrock. Thick outwash deposits have been incised by the river to form two to five flights of paired terraces; the lower two terrace levels date to <3500-4000 and <2530 ± 250 years BP. These reaches are now characterized by relatively low gradients, and post-incision lateral migration of the river has been minimal. Narrower and steeper valley sections, where bedrock is gneissic and outwash deposits are thin, have only unpaired terraces. These terraces form in response to progressive lateral migration of the channel, which is limited by the bedrock valley sides.

Connecticut Council on Soil and Water Conservation. 1979. "The Erosion and Sediment Source Inventory For the State of Connecticut," Report prepared for the US Environmental Protection Agency, Grant No. 001-10-801.

This report summarizes results of an inventory of measured soil loss at disturbed sites throughout Connecticut. The study focused on soil loss from cropland, construction sites, streambanks, road embankments and surface mines. Urban areas were excluded from the sample. The Universal

Soil Loss Equation was used to estimate the amount of erosion at each site. The entire population of construction sites, cultivated lands, and surface mines above a threshold size were sampled; stream and road banks were sub-sampled. Inherent in the study design were two limitations to the application of this work to determining sediment loads in the Naugatuck River. First, the inventory was designed to determine soil loss in excess of geologic erosion at any specific site, rather than the total erosion. Second, no attempt was made to determine how much of the eroded soil was delivered to any watercourse (the sediment delivery ratio). Estimates of soil loss are tabulated within soil and water conservation districts, by township and major drainage basin for each of the sources listed above. Best management practices for controlling erosion in each conservation district are also discussed.

Kulp, K. P. 1983. "Suspended Sediment Characteristics Of the Yantic River At Yantic, Connecticut," Connecticut Water Resources Bulletin No. 39, Connecticut Department of Environmental Protection, Hartford, CT.

Daily streamflow and suspended sediment data, collected on the Yantic River at Yantic during the 1976 through 1980 water years, show that the current minimum suspended sediment yield in the basin is 43.5 tons/mi^2/yr. Correcting for the lowest major impoundment in the watershed, Fitchville Pond, gives an estimate of the actual average suspended sediment yield of between 50-60 tons/mi^2/yr. The basin is underlain by crystalline igneous and metamorphic rocks, with a discontinuous mantle of glacial till and stratified drift. Slopes are moderate (only locally reaching 35%), and relief is less than 400 ft. Land use types were distributed throughout the 97.6 mi^2 watershed as follows: urban, 4.7%; open, cleared land, 16.8%; cultivated land, 17.8%; water and wetlands, 5.9%; and forest, 54.8%. Although slightly steeper, the upper basin of the Naugatuck River (above Waterbury) is relatively similar in other respects to the Yantic River watershed. Therefore, the estimated annual suspended sediment yield of the upper Naugatuck basin is likely to be in the range of 50-70 tons/mi^2/yr.

Patton, P. C. 1981. "Geomorphic-Hydrologic Methods For Assessing Flood Potential In Southern New England," Technical Completion Report, OWRT Project No. A-078-CONN, Wesleyan University, Middletown, CT.

Debris fans from tributary mouths, Holocene terrace deposits, and active floodplains were evaluated regarding their usefulness as indicators of paleohydrologic events. Debris fans were found to be formed during relatively high frequency/moderate discharge events (ex., ~Q20) relating to flushing of discrete reaches in the tributaries. However, their stratigraphy was found to be complex, relating both to the hydrologic regime of the tributary and the main stem. These fans represent current watershed conditions, and are not good indicators of discrete, very large floods. Slackwater deposits are associated with two geomorphic environments: the mouths of certain tributaries which were hydraulically dammed during passage of a flood wave on the mainstem; and upstream of major bedrock constrictions, particularly on the Shepaug River, where locally thick sequences of fine grained overbank sediments overlying multiple buried soil A horizons can be found. Interestingly, the floodplains below these constrictions are topographically very irregular, and show the remnants of scour holes, and both transverse and longitudinal gravel bars. Gravel thickness and grain size decrease away from the stream channel. Apparently, these deposits were rapidly formed as water emerged from the constricted reaches. The overall valley morphology has developed due to localized, rather than regional, conditions.

Thomson, M. T., Gannon, W. B., Thomas, M. P., Hayes, G. S., and others. 1964. "Historical Floods in New England," U.S. Geological Survey Water-Supply Paper 1779-M, Washington, DC.

This paper presents quotations from diarists and newspaper accounts of historic floods through October, 1955. These give information on flood dates and (approximate) stages. The records are indexed by year and primary river basin in which the floods occurred. Included where available are estimates of peak flood discharge based on engineering analysis of reoccupied locations noted in the archival accounts.

Wilson, W. E., Burke, E. L., and Thomas, C. E. Jr. 1974. "Water Resources Inventory Of Connecticut: Part 5 - Lower Housatonic River Basin," Water Resources Bulletin No. 19, Connecticut Department of Environmental Protection, Hartford, CT.

This report summarizes surface and groundwater data in the Housatonic River watershed below the confluence with the Shepaug River. Frequency and duration of high and low flows, water quality and temperature data, aquifer yields, and inter- and intrabasin diversions for water supply purposes are all presented in graphic or map form. The narrative puts these data in coherent, basin-wide context, but is too general for use in site-specific analysis without going to the original data sources. The primary purpose of this report is for use in general basin-wide planning.

Valleta, W. 1976. "Surface Mining In Connecticut: The Public Need For Planning and Regulation For Sand and Gravel Operations," Unpublished report prepared for the Central Naugatuck Valley Regional Planning Agency, 94 p.

Concern that sand and gravel is a limited resource in the Naugatuck valley leads to the necessity for extraction planning. Limits on the resource are placed by the economic need for production near consumption, by the limited amount of non-riverine glaciofluvial material suitable for commercial use in the valley, and by strongly competing land uses in the floodplain and wetlands which are the major current source of sand and gravel. As a result, crushed quarry rock is likely to be the next major source of sand and gravel in the valley. Planning mechanisms may be developed by both local jurisdictions and the state Dept. of Environmental Protection. Legal justification for planning in Connecticut is outlined. Current planning does not consider serial land uses (ie., with sand and gravel extraction an intermediate land use); the author contends that this is a necessary component of an overall strategy for earth resource (sand and gravel) management.

Wolman, M. G. and Eiler, J. P. 1958. "Reconnaissance Study of Erosion and Deposition Produced By the Flood of August 1955 In Connecticut," Transactions, American Geophysical Union, Vol 39, No. 1, pp. 1-14.

This study documents field evidence on the magnitude and spatial frequency of erosion and deposition from the flood based on field observations made immediately after the 1955 floods. The study concentrated on the Farmington River valley, immediately west of the northern Naugatuck River watershed. The authors found surprisingly little erosion or deposition in either uplands or river valleys relative to the magnitude of flooding (which was the largest flood since European settlement). Erosion was concentrated in narrow, steep valleys, primarily in headwater areas but also in bedrock or manmade constrictions. Deposited sediment was derived from local valley sources, particularly valley walls and outwash terraces, was generally fine sand, and occurred as overbank deposits or fans at the base of low order channels.